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ATOMIC ENERGY OF CANADA LIMITED

Technical Memorandum

SUBJECT: Development of an Ultrasonic Defect Detection and Imaging System for Weld Inspections (CANMET ref: 23440-4-9245-FE)

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ABSTRACT: This report provides project background and describes work progress up to the end of 1985 February.

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1. INTRODUCTION

A "Sector B-Scan" imaging system was conceived at CRNL and a laboratory prototype system (see Figure 1), built for assessing the viability of the approach. The system has demonstrated sufficient promise to warrant further development, into a weld inspection tool for field use. Because these developments appeared to have direct relevance to their program "Research on Materials for Offshore Structure and Arctic Vessels - Steels", CANMET were invited to participate in project funding.

System development plans are outlined in the original work proposal(1). Individual tasks include:

i) Task A1 - Optimization of Lens/Wedge Configuration
ii) Task A2 - Distance/Amplitude, Incidence/Amplitude Correction
iii) Task B - Intermediate Evaluation of the System
iv) Task C - Prototype Scanner Development
v) Task D - Prototype Evaluation
vi) Task E - Field Testing
vii) Task F - Reporting

Funding has been authorized for completion of work up to and including Task B. Unfortunately work has been delayed because of a misunderstanding about project approval(2) and work on Task A1 was started at the beginning of February 1985. Task A1 has now been successfully completed and the first "decision" point overcome. Work is therefore continuing on Task A2 and Task B. This report describes the work performed in completing Task A1.

This project is cost shared 50/50 between CANMET and CRNL, in support of CANMET's Offshore Steel Program and CRNL's vote funded research program.

2. OBJECTIVE

The objective of Task A1 was the optimization of the Sector-Scanner, lens/wedge configuration to reduce the high level of acoustic noise, which at certain angles of incidence, obliterated defect signals from the test piece.

3. BACKGROUND

The original Sector Scanner lens/wedge design is shown diagrammatically in Figure 2. It consists of a semi-circular block of polystyrene; the contact wedge, upon which runs a polystyrene shoe, to which is glued an acrylic, compound lens. The lens and shoe are attached through a suitable coupling medium to a standard, off-the-shelf ultrasonic transducer. The transducer/lens/shoe assembly is ultrasonically coupled to the wedge and is moved around the wedge by a stepping motor controlled automatically by a micro-processor (also used for data acquisition, processing and data imaging) to achieve a continuous, variable angle or "Sector-Scan". Ultrasonic A-scans are digitized and beam angles in the test piece are calculated for each increment

of angular movement. The A-scans are then plotted at these angles using increasing grey intensities for increasing signal amplitude, to produce an image of the test piece similar to that on the monitor in Figure 1. Images can also be printed-out on the EPSON printer.

The compound lens was intended to increase the effective working range of a single transducer/lens combination and thereby maintain depth of focus of the ultrasonic beam, at high angles of incidence. For an explanation, see Figure 3.

Although promising in concept, the system is plagued by sound reverberations within the lens, shoe and wedge which appears as acoustic noise on the Ultrasonic instrument and can, at certain angles, completely obscure defect indications from the test piece, or cause "false" indications. These problems can be readily appreciated, by referring to Figure 4, which shows A-scans using the lens/shoe/wedge arrangement, shown in Figure 2, at angles of incidence of 0°, 30° and 45°. Much of the noise, is due to poor impedance matching, at the various material interfaces, compounded by the semi-circular shape of the wedge, which efficiently directs internally reflected sound, within the wedge, back to the transducer. Methods by which reductions in acoustic noise may be achieved include:

i) Selection of lens and wedge materials with better acoustic impedance matching.

ii) Incorporation of quarter-wave plates for impedance matching.

iii) Modifying wedge shape to prevent internally reflected sound within the wedge returning to the transducer.

iv) Restricting inspection to those angles least affected.

v) Ultrasonic Immersion testing.

4. INVESTIGATIONS TO REDUCE ACOUSTIC NOISE

Methods involving changes to the wedge shape or restricting inspection angles were dismissed because they undermined the basic "Sector-Scan" concept. Such methods would only be employed as a last resort and even then any advantage that Sector-Scanning might have over standard Ultrasonic test methods would be severely limited and further development on this basis would be difficult to justify.

Alternative Materials

A survey of alternative materials for lens, shoe and wedge was carried out in an attempt to improve acoustic impedance matching. However, none of the more common materials possessed the required impedance matching qualities, in combination with low compression wave velocity (to generate shear waves in carbon steel test piece) and good sound transmission qualities. A thorough investigation into material acoustic properties is a research topic in its own right and was considered to be outside the scope of this project.

Quarter Wave Plates

Selection of materials for use as quarter wave plates depends upon the material acoustic impedances(3). Sound transmission will be a maximum when

$$Z = \sqrt{Z_I Z_T}$$

where Z = quarter wave plate material impedance
Z_I = incidence material impedance
Z_T = test material impedance,

but providing $Z_I > Z > Z_T$ some improvement in sound transmission should result.

Acoustic impedances of steel and polystyrene are 45×10^6 kg/m^{2}s and 2.5×10^6 kg/m^{2}s, respectively. Therefore, for best results materials with acoustic impedances of about 10.6×10^6 kg/m^{2}s are required. However, any materials with acoustic impedance in the range 2.5×10^6 to 45×10^6 kg/m^{2}s should improve sound transmission and thereby reduce noise. In addition, to ensure shear wave generation in the test piece (steel) compression wave velocity of the quarter-wave material should be less than or equal to, the shear wave velocity of steel (3.23 km/s). Lead, with acoustic impedance of 25 kg/m^{2}s and compression wave velocity of 2.16 km/s was the only readily available material meeting the above criteria, although tin, with acoustic impedance of 24 kg/m^{2}s and compression wave velocity of 3.32 km/s, was considered near enough to warrant consideration.

Quarter-wave plates were therefore fabricated in both lead and tin, and each in turn was inserted between the contact wedge and test piece, with suitable couplant. Neither of the materials achieved the desired effect; and in fact sound transmission into the test piece appeared to be impeded in both cases. Clearly application of quarter-wave theory requires a more detailed experimental study. The passage of sound from the transducer through the lens, shoe and wedge into the test piece involves transmission across eight material interfaces: transducer/couplant, couplant/lens, lens/glue, glue/shoe, shoe/couplant, couplant/wedge, wedge/couplant and couplant/test piece. Each of these material interfaces is a potential source of noise and impedance matching at each interface by either material selection or quarter-wave effects would involve significant effort.

Immersion Testing

A reduction in the number of material interfaces, was considered, the most effective way of reducing sound reverberations and interfering noise. As a first step, the contact wedge was removed and the transducer, with lens and shoe only, was operated under water. This effectively eliminated two material interfaces and resulted in significant noise reduction, as shown in Figure 5. Further improvement; Figure 6, was obtained by replacing the lens and shoe with a compound lens, designed specially for immersion testing, which removed another two material interfaces. However, near surface resolution at 0° was limited and several noise spikes (probably due to edge

effects at the change in lens radius) were still present. Best results; Figure 7, were obtained using a standard immersion transducer focussed at about 25 mm in steel, which gave a similar focal depth as the lenses used. This provided good near surface resolution and eliminated noise spikes.

5. CONCLUSIONS AND COMMENTS

Noise has been reduced to an acceptable level and therefore further work is continuing. Because of its obviously better acoustic noise properties compared with the transducer/lens combinations, future work will be undertaken using the focussed, immersion transducer. This means sacrificing the advantage of the compound lens in maintaining depth of focus, and immersion testing also entails some complication of scanner design for a field system. However, it may be possible to maintain focal depth by adjusting the water path as the inspection angle changes. Mechanisms which will do this are being investigated, together with methods for adapting the immersion technique for field use.

In the meantime work is progressing on Task A2 to produce Distance/Amplitude and Incidence/Amplitude correction curves, using the response of the immersion transducer, at different inspection angles, to side drilled holes, of different depths. Normally, defect response diminishes with increasing material depth but the effects of changing inspection angle on side drilled hole response are unknown. Correction data will be incorporated into the system software so that defects of similar size but detected at differing angles and depths will be displayed at similar intensities.

6. REFERENCES

1. Proposal for the Development of an Ultrasonic Defect Detection and Imaging System for Weld Inspections (DSS File No. 15 SQ.23440-3-Offshore-Steel), Submitted by: Atomic Energy of Canada Limited - Research Company, Chalk River Nuclear Laboratories to Supply and Services Canada, 1983 November.

2. Letter from J. Mackwood to Dr. M. Sahoo, 1985 March 12.

3. Frederik J.R., Ultrasonic Engineering, p. 284, John Wiley & Sons, Inc. 1965.

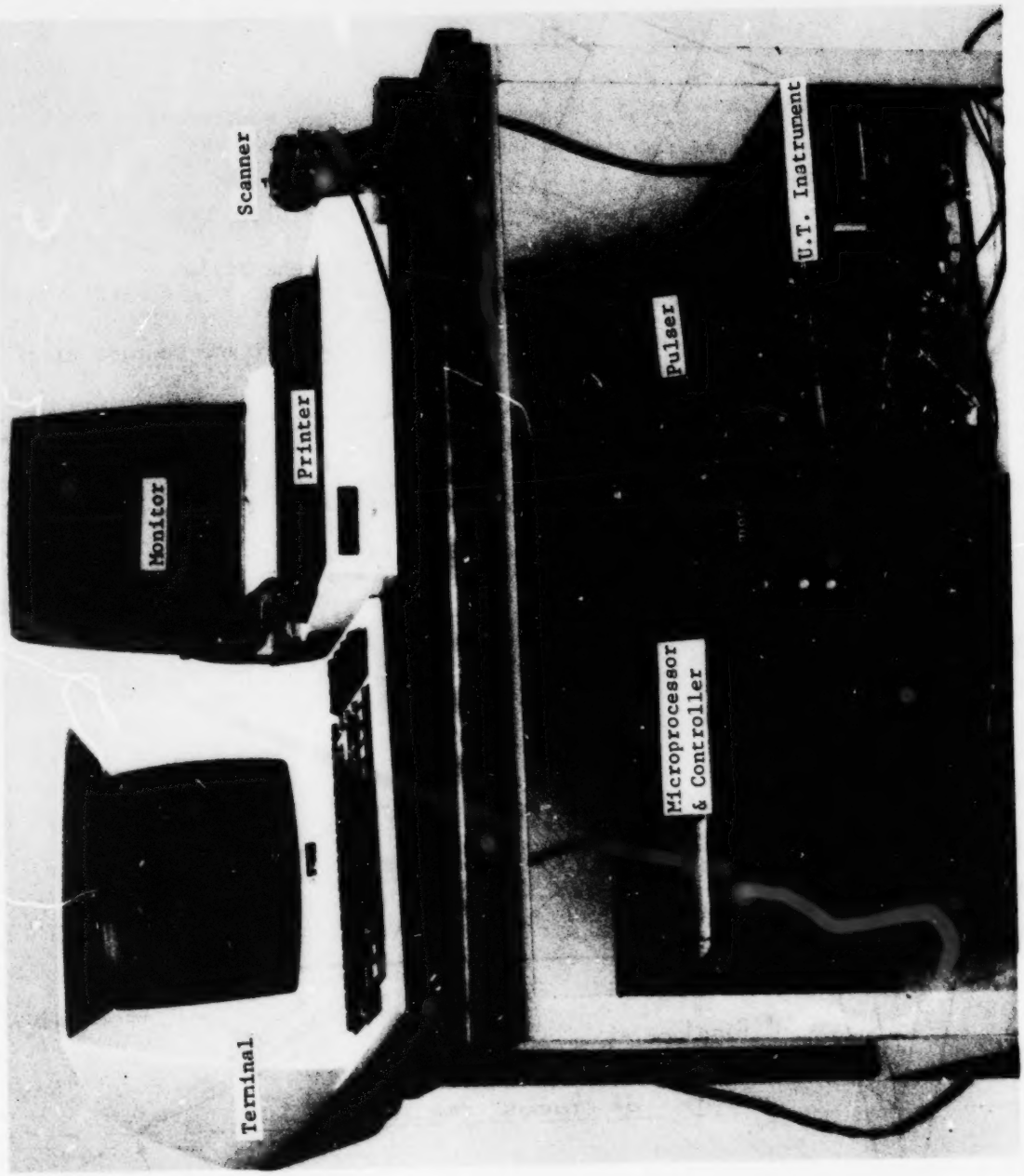

FIGURE 1: SECTOR SCANNING SYSTEM - LABORATORY PROTOTYPE

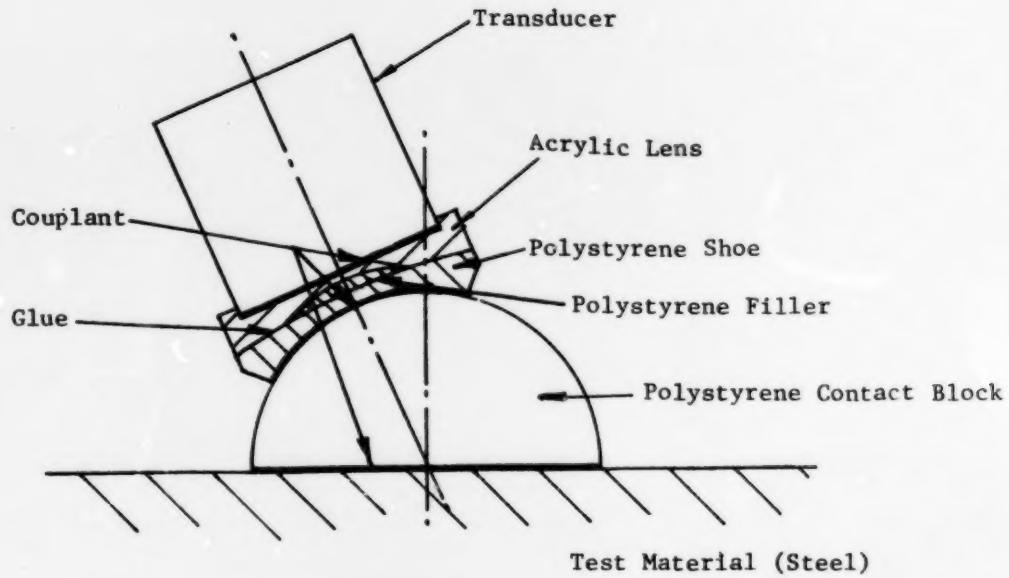

FIGURE 2: SECTOR SCANNER LENS/WEDGE ARRANGEMENT

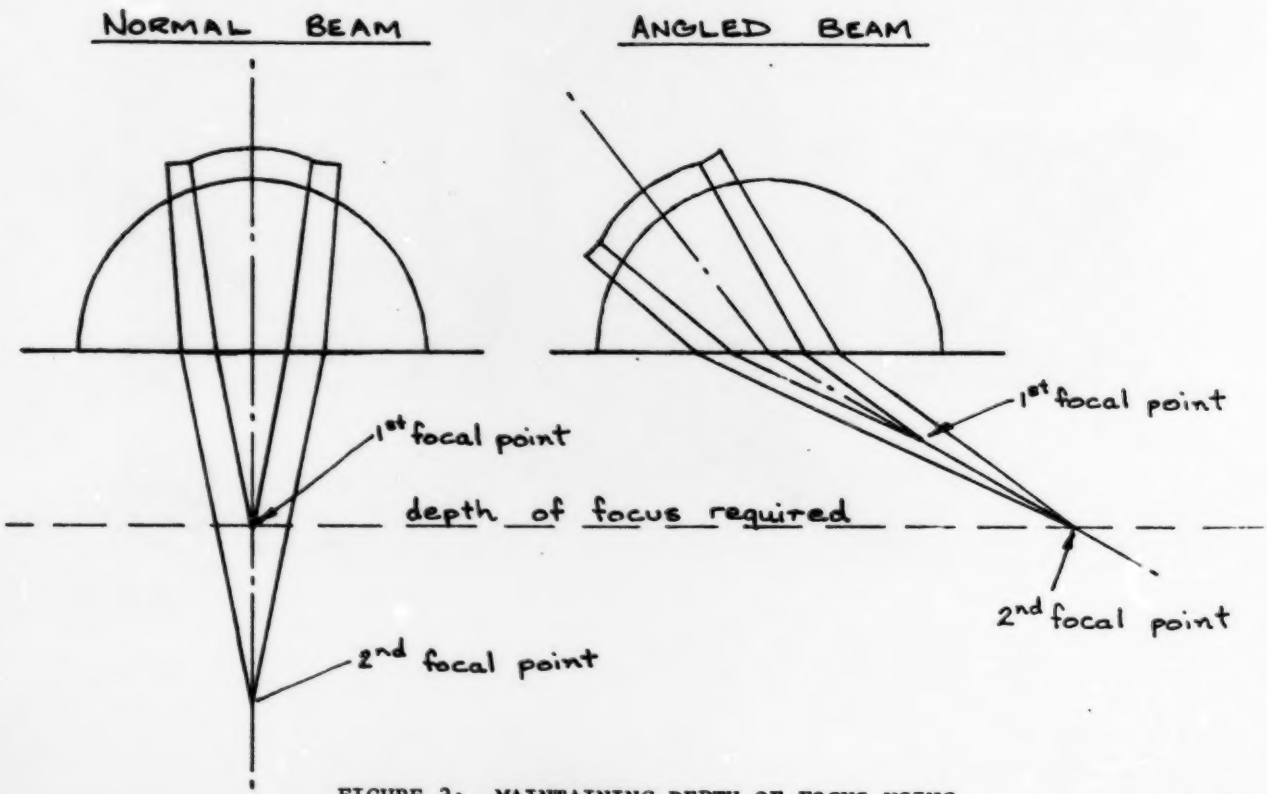

FIGURE 3: MAINTAINING DEPTH OF FOCUS USING COMPOUND LENS

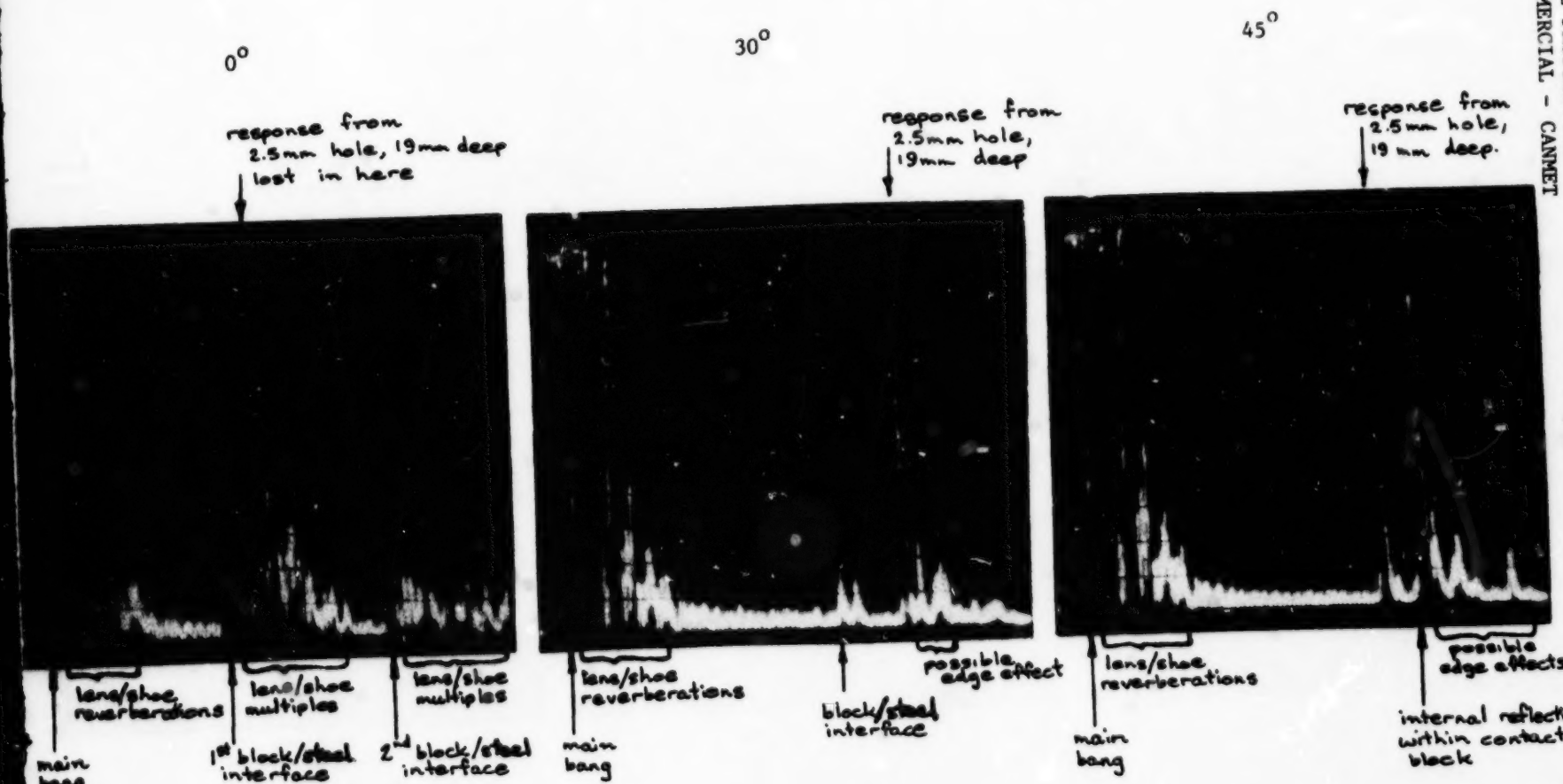

FIGURE 4: A-SCANS FOR ORIGINAL CONDITIONS

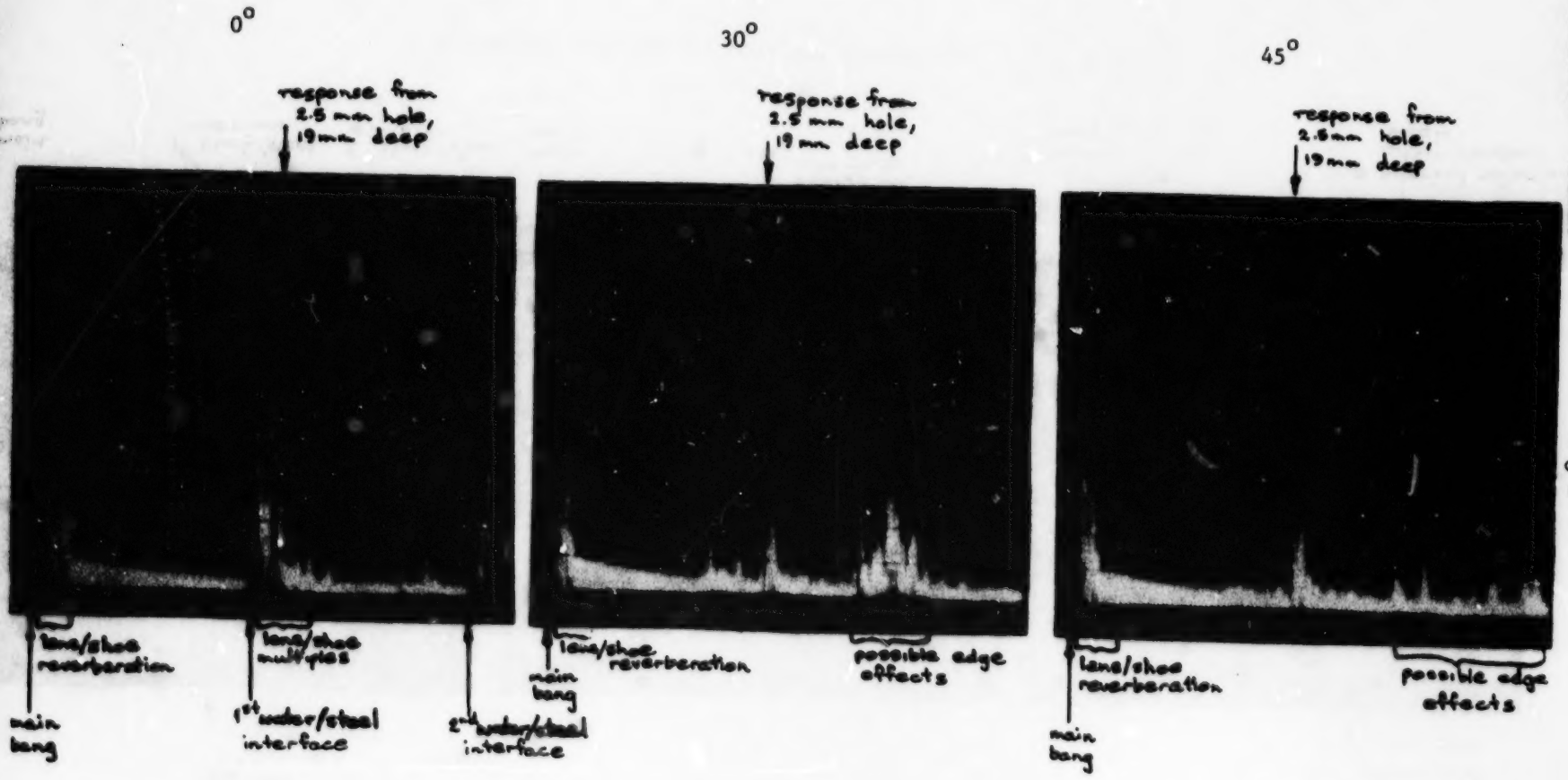

FIGURE 5: A-SCANS WITH CONTACT BLOCK REMOVED - IMMERSION

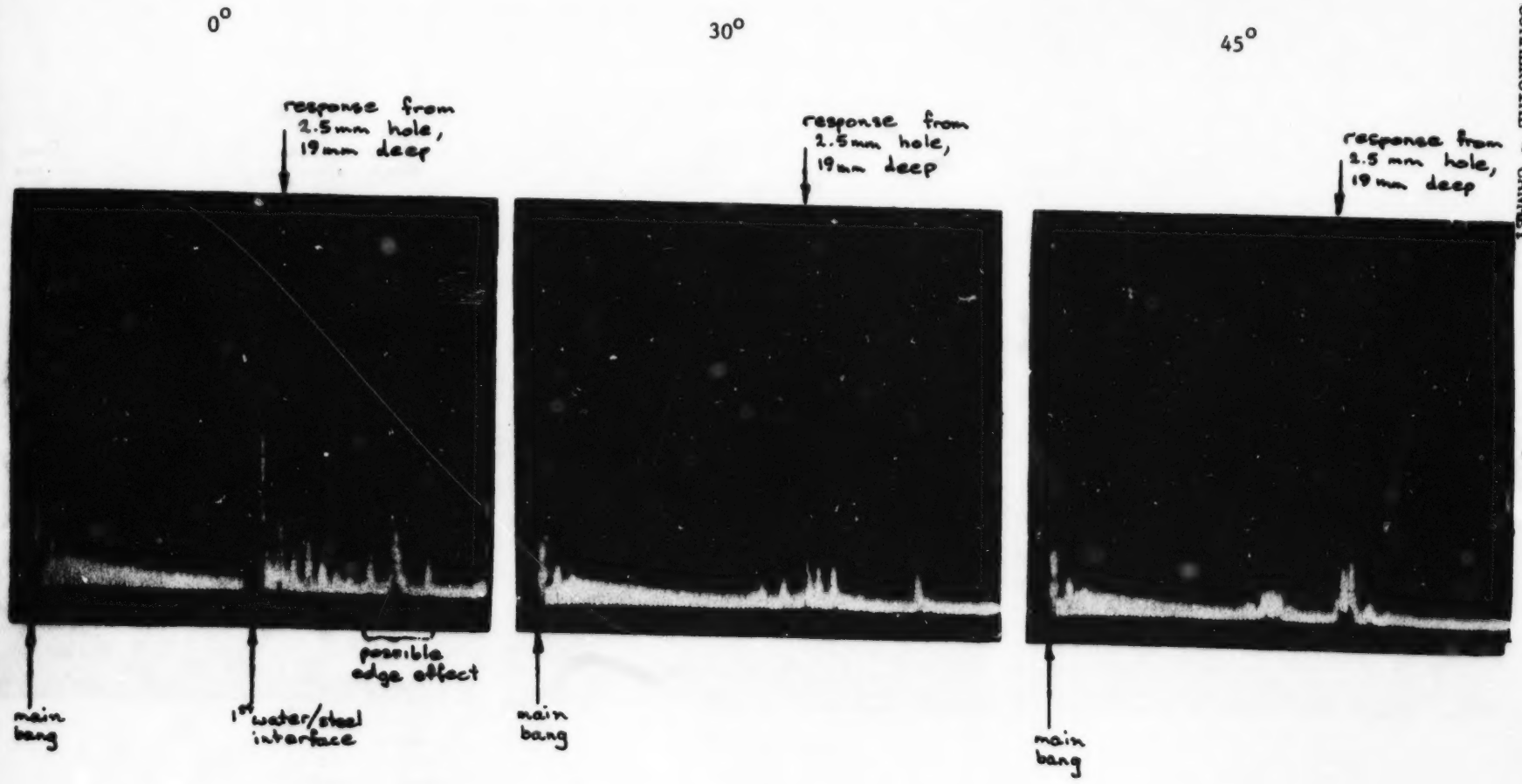

FIGURE 6: A-SCAN WITH IMMERSION LENS

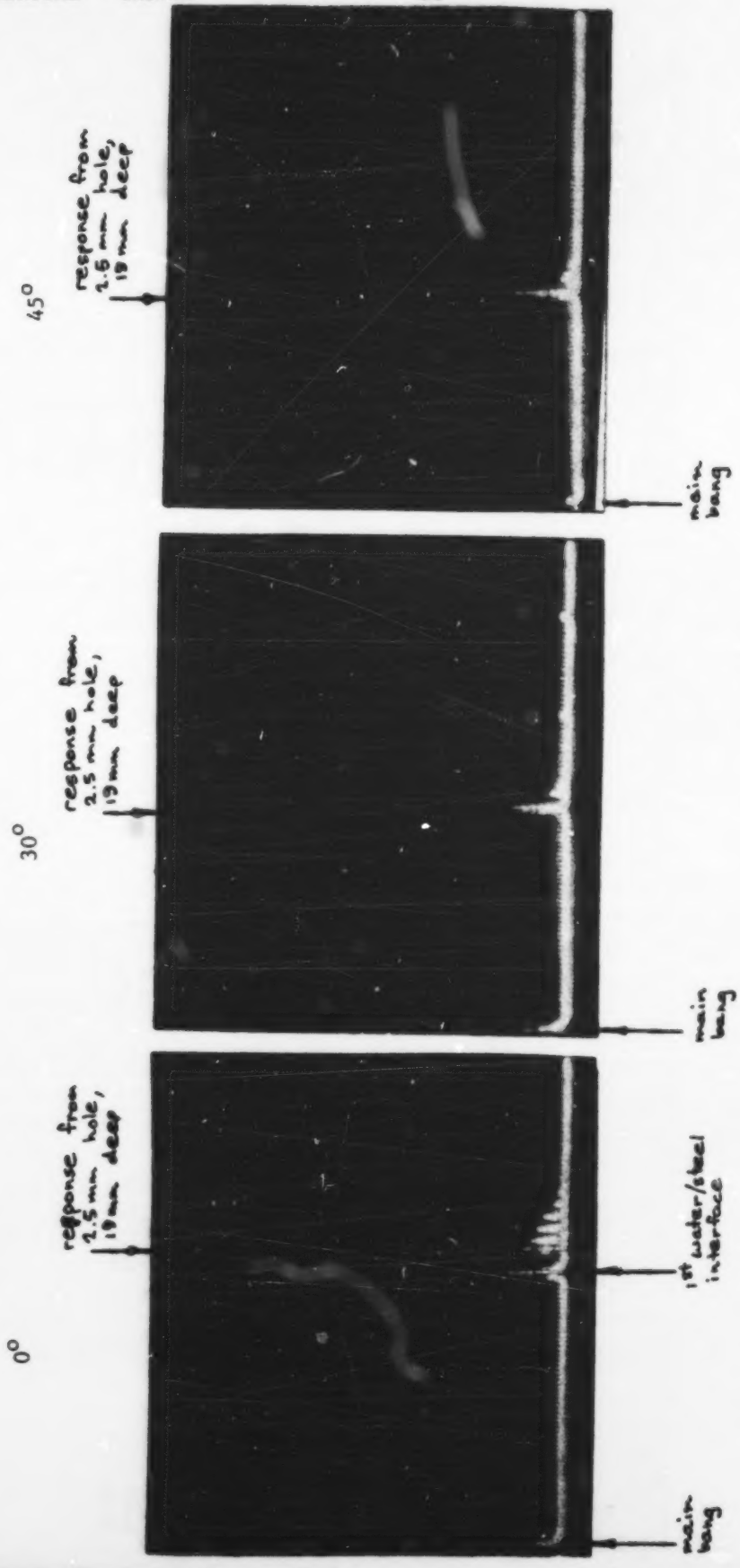

FIGURE 7: A-SCANS WITH FOCUSSED IMMERSION TRANSDUCER